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(54) **Semiconductor base and its manufacturing method, and semiconductor crystal manufacturing method**

Halbleiterbasis ihre Herstellung und Halbleiterkristallhersetllungsmethode

Base de semiconducteur et son procédé de fabrication et procédé de fabrication de cristal semiconducteur

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## Description

### Technical Field

**[0001]** The present invention relates to a semiconductor base, a manufacture method thereof and a manufacture method of a semiconductor crystal. More particularly, this invention relates to a structure and a method useful when using a semiconductor material susceptible to dislocation defects.

### Background Art

**[0002]** For crystal growth of a GaN group material, a substrate free of lattice match, such as sapphire, SiC, Spinel, recently Si and the like, is used, because there is no substrate that lattice matches with GaN group materials. However, a manufactured GaN film contains dislocations amounting to $10^{10}$ dislocations/$cm^2$ due to the absence of lattice match. While high luminance light emitting diodes, semiconductor lasers and the like have been realized in recent years, reduction of a dislocation density is desired for achieving improved properties.

**[0003]** To avoid defects, such as dislocation and the like, caused by different lattice constant and the like, the same crystal as the material to be crystal grown is used. For example, for crystal growth of a GaN group semiconductor, a GaN substrate is used. However, a large-sized product has not been obtained, and therefore, sapphire and the like are actually used as a substrate. There has been proposed a method in recent years, wherein, for vapor phase growth on a GaN base layer grown on sapphire, the aforementioned base layer is partially masked to effect a selective growth for crystal growth in a lateral direction, whereby a high quality crystal having a reduced dislocation density is obtained (e.g., JP-A-10-312971). By growing this film thick and separating and removing the substrate, a GaN crystal can be obtained. Due to the problem of occurrence of cracks and breakage of substrate resulting from differences in lattice constant and in thermal expansion coefficient, a substrate having a large area has not been obtained.

**[0004]** The above-mentioned JP-A-10-312971 discloses a method for obtaining a film having a reduced dislocation density. However, a new problem has been found that, in the part grown in a lateral direction on a mask layer, the C axis tilts in a slight amount toward the direction of lateral growth, and degrades the crystal quality (Abstracts of MRS 1998 Fall Meeting G3.1). This can be confirmed through measurement (¢ scan) of the incident orientation dependency of X-ray rocking curve measurement (XRC). That is, a full width at half-maximum (FWHM) of X-ray rocking curve by incident X-ray from the direction of lateral growth is greater than the FWHM value by X-ray from a stripe direction of a mask layer, which means the presence of orientation dependency of the micro tilting of the C axis. This suggests a possibility of inducing a number of new defects in the junction part of the lateral growth on the mask.

**[0005]** As the mask layer material, $SiO_2$ is generally used. A problem has been clarified that, when a layer is laminated thereon by crystal growth, the Si component transfers into the crystal growth layer, constituting a problem of autodoping contamination.

**[0006]** When a semiconductor material containing Al, such as AlGaN, is grown on a substrate containing an $SiO_2$ mask layer, crystal growth occurs on the mask layer, too, preventing effective selective growth itself.

**[0007]** In an attempt to solve such a problem, a method has been proposed wherein a stripe groove processing is applied to a substrate having a buffer layer and a GaN layer formed on an SiC base substrate, which groove reaches the SiC layer to form a convex, and crystal growth is done from the GaN layer on the top of this convex (Abstracts of MRS 1998 Fall Meeting G3.38). According to this method, a selective growth without an $SiO_2$ mask layer is possible, whereby various problems caused by the use of the aforementioned $SiO_2$ mask can be overcome.

**[0008]** For the above-mentioned method, a sapphire substrate can be used as the base substrate and the method thereof has been disclosed (e.g., JP-A-11-191659). The above-mentioned method requires steps of crystal growing a buffer layer material and a GaN group material on a sapphire base substrate, taking the substrate out from a furnace for growth, applying a groove processing, and crystal growing again, thus posing a new inconvenience of complicated production process, increased number of steps, higher cost and the like.

**[0009]** An attempt has been also disclosed in the (Abstracts of the Japan Society of Applied Physics 99 autumn 2P-W-8) wherein a step is made on a GaN substrate and embedding growth is performed to secure a region having a low dislocation density. In this case, a low dislocation density region is formed in a part of the embedded layer.

**[0010]** To obtain a low dislocation density region by the above-mentioned method, however, the intervals between convex parts need to be widened or the depth of concave part needs to be increased. To this end, the layer needs to be grown thick by embedding for a long time, which in turn intrinsically poses various problems of occurrence of cracks due to the thick film forming, costly manufacture due to the long time spent, and the like.

**[0011]** There is also an attempt to crystal grow a GaN group material on an Si substrate. However, growth of a GaN group crystal results in cambers and cracks caused by difference in the thermal expansion coefficient, thereby preventing crystal growth having a high quality.

**[0012]** It is therefore an object of the present invention to avoid various problems caused by ELO growth using a conventional mask layer and achieve simplification of the production process, in view of the above-mentioned problems. The present invention also aims at solving the problems caused by the embedding growth of a step structure without a mask. In addiction, the present invention aims at solving the problem of selective growth of AlGaN, which has been conventionally unattainable. The present invention further aims at suppressing the occurrence of cambers and cracks associated with the use of an Si substrate and the like.

**[0013]** In view of the above-mentioned problems, it is an object of the present invention to provide a GaN crystal having a large area. The present invention also aims at avoiding carious problems caused by the ELO growth using a conventional mask layer and simplifying the production process. ZHELEVA T S ET AL 'Pendeo-epitaxy-a new approach for lateral growth of gallium nitride structures' MRS INTERNET JOURNAL OF NITRIDE SEMICONDUCTOR RESEARCH, MATERIALS RESEARCH SOCIETY, WARRENDALE, PA, US, vol. 451, 30 November 1998 (1998-11-39) XP002117241 ISSN: 1092-5783 discloses a method for epitaxially growing GaN layers which comprises the following steps:

(a) a buffer layer and a GaN layer are formed on a SiC substrate to give a layered substrate;
(b) a convex part is formed by making stripe grooves by etching from the surface of the above-mentioned GaN layer to the SiC substrate;
(c) a GaN crystal is re-grown from the surface of the GaN layer remaining as an upper part of the above-mentioned convex part with the GaN as seed crystal.

**[0014]** US-A-5,676,752 discloses a method of producing sheets of crystalline material as well as devices employing such sheets. In the method, a growth mask is formed upon a substrate and crystalline material is grown at areas of the substrate exposed through the mask and laterally over the surface of the mask to form a sheet of crystalline material.

**[0015]** The sheet is optionally separated so that the substrate can be reused. The method has particular importance in forming sheets of crystalline semiconductor material for use in solid state devices.

## Disclosure of the Invention

**[0016]** The present invention relates to a semiconductor base comprising a single material substrate and a layer of semiconductor crystal formed on said substrate by vapor phase growth, wherein
a crystal growth plane of the substrate is processed by etching to give a concavo-convex surface,
the semiconductor crystal is a GaN group semiconductor crystal defined by $Al_x Ga_{1-x-y} In_yN$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$) which is grown from an upper part of the convex part of the concavo-convex surface and the concave part of the concavo-convex surface, and
the semiconductor crystals grown in the lateral direction from the upper part of the convex part are joined to cover said concavo-convex surface while leaving a cavity between the layer and the semiconductor crystal grown from the concave part.

**[0017]** It is preferable that the convex parts of the crystal growth plane of the above-mentioned substrate form parallel stripes.

**[0018]** It is more preferable that the above-mentioned semiconductor crystal be InGaAlN and the longitudinal direction of the stripe be in parallel to the (1-100) plane of the InGaAlN crystal.

**[0019]** The present invention further relates to a method for manufacturing a semiconductor base comprising a single material substrate and a semiconductor crystal formed on said substrate which is a GaN group semiconductor crystal defined by $Al_x Ga_{1-x-y} In_yN$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$), which method comprises
preparing a single material substrate having a concavo-convex surface formed by etching,
supplying an ingredient gas to the substrate to grow, by vapor phase, crystals from the upper part of the convex part of the concavo-convex surface and the concave part of the concavo-convex surface, and joining the semiconductor crystal grown in the lateral direction from the upper part of said convex part thereby covering said concavo-convex surface with the joined crystal in such a manner that a cavity is formed between the joined crystal and the crystal grown from the concave part.

**[0020]** The present invention further relates to a method for manufacturing a semiconductor crystal, which method comprises preparing a semiconductor base as mentioned above, and separating the semiconductor crystal from the substrate at a cavity formed between the semiconductor crystal layer and the concave part, to remove the semiconductor crystal layer.

**[0021]** Preferred embodiments of the invention are apparent from the dependent claims.

**[0022]** The manufacturing method of the semiconductor crystal of the present invention is characterized in that a crystal growth plane of the substrate is processed to have a concavo-convex surface and a semiconductor crystal is formed by vapor phase crystal growth from an upper part of a convex part of the concavo-convex surface to cover the concavo-convex surface, thereby giving a laminate having a cavity between the semiconductor crystal layer and the concave part of the aforementioned concavo-convex surface, and that the semiconductor crystal is separated from the substrate at the aforementioned cavity. In this case, the above-mentioned semiconductor crystal is preferably InGaAlN.

**[0023]** According to the manufacturing method of the semiconductor crystal of the present invention, a step for forming a semiconductor crystal as in the manufacturing method of the semiconductor base of the present invention may be repeated plural times.

## Brief Description of Drawings

**[0024]**

FIG. 1 is a sectional view explaining the state of crystal growth of the semiconductor base, wherein 1 is a substrate, 11 is a convex part, 12 is a concave part, 13 is a cavity and 2 is a semiconductor crystal layer.

FIG. 2 is a sectional view explaining the state of crystal growth of the semiconductor base of the present invention.

FIG. 3 is a sectional view explaining the state of crystal growth of the semiconductor base not according to the present invention.

FIG. 4 is a graph showing the θ scan data of XRC.

FIG. 5 is a sectional view explaining the state of crystal growth of the semiconductor base not according to the present invention.

FIG. 6 is a sectional view explaining the state of crystal growth of the semiconductor base and the manufacturing method of the semiconductor crystal of the present invention, wherein 3 is a mask (not according to the invention).

FIG. 7 is a sectional view explaining the state of crystal growth of the semiconductor base and the manufacturing method of the semiconductor crystal (not according to the present invention).

FIG. 8 is a sectional view explaining the state of crystal growth of the semiconductor base (not according to the present invention).

FIG. 9 is a sectional view explaining the state of crystal growth of the semiconductor base (not according to the present invention).

FIG. 10 is a sectional view explaining a different embodiment of the manufacturing methods of the semiconductor crystal (not according to the present invention).

## Detailed Description of the Invention

**[0025]** The present invention is characterized in that a substrate surface permitting lateral growth capable of substantially forming a low dislocation region is provided from the start of the crystal growth, by forming a concavo-convex surface on a substrate, on which even a buffer layer has not been formed. When the substrate is constituted in this way to allow vapor phase growth of crystals, the crystal growth can occur in the entirety of the substrate surface at the initial stage of growth. With the progress of the growth, the growth dominantly occurs in an upper part of a convex part, as a result of which diffusion of the starting material into the concave does not occur easily and the above-mentioned concavo-convex surface is covered with a layer grown exclusively from the upper part of the convex part. In the growth starting from the convex part, the growth in the perpendicular direction to the C axis (so-called lateral growth) occurs, thereby forming a substantially low dislocation region without using a mask layer, unlike the conventional manner. Therefore, by merely forming a concavo-convex surface on the substrate, successive growth is achieved by, for example, growing a buffer layer and then a GaN layer.

**[0026]** The manufacturing method of the semiconductor crystal of the present invention is first characterized by the growth of a semiconductor crystal by the same process as the manufacturing method of the above-mentioned semiconductor base. As mentioned above, the crystal growth in the concave part of the substrate can be suppressed, and therefore, a cavity is formed between the substrate and the semiconductor crystal. As a result, the contact area between the substrate and the semiconductor crystal can be decreased, which in turn markedly reduces the strain caused by the differences in the lattice constant and thermal expansion coefficient. This secondly characterizes the manufacturing method of the semiconductor crystal of the present invention. This has an effect that the occurrence of cracks and breakage can be suppressed and a semiconductor crystal having a large area can be obtained. In addition, because the above-mentioned strain focuses on the contact part between the substrate and the semiconductor crystal, the substrate and the semiconductor crystal can be separated efficiently.

**[0027]** The embodiment of the present invention is explained in detail in the following by referring to the drawings. Only Figure 2 is representative of the present invention.

**[0028]** FIG. 1 (a)-(c) and FIG. 6 (a)-(c) are sectional views explaining the state of crystal growth of the semiconductor base. FIG. 6 (a)-(d) are sectional views explaining the manufacturing methods of the semiconductor crystal.

**[0029]** In the Figures, 1 is a substrate, 2 is a semiconductor crystal which is vapor phase grown on the substrate 1. On the crystal growth plane of the substrate 1, a convex part 11 and a concave part 12 are formed, so that crystal growth proceeds exclusively from an upper part of the aforementioned convex part 11. In the embodiment of FIG. 6, the concave part 12 is covered with a mask 3 on which the crystal cannot substantially grow.

**[0030]** The substrate of the present invention is a base on which to grow various semiconductor crystal layers, and on which even a buffer layer for lattice match has not been formed. Examples of such substrate include sapphire (C-plane, A-plane, R-plane), SiC (6H, 4H, 3C), GaN, Si, Spinel, ZnO, GaAs, NGO and the like. As long as the object of the invention is achieved, other materials may be used. It is also possible to use one stripped from these substrates.

**[0031]** A semiconductor crystal to be grown on the substrate 1 is $Al_xGa_{1-x-y}In_yN$ ($0 \leqq x \leqq 1$, $0 \leqq y \leqq 1$). Those having different x, y composition ratios, such as GaN, $Al_{0.5}Ga_{0.5}N$, $In_{0.5}Ga_{0.5}N$ and the like, are exemplified.

**[0032]** In the case of a semiconductor material containing Al, such as AlGaN and the like, the conventionally unattainable lateral growth of AlGaN has been made possible, because the problem of growth on an $SiO_2$ mask layer, which is associated with the conventional mask method, can be overcome by the maskless method of the present invention, and therefore, a high quality film having a low dislocation can be grown directly on the substrate. As a result, absorption of light due to GaN layer, which is problematically found in an ultraviolet emitting element and the like, can be obliterated, which is particularly preferable in practice.

**[0033]** It is advantageous that the convex part 11 formed on the crystal growth plane of the substrate 1 have such a shape as permits crystal growth exclusively from an upper part thereof. As used herein, by the "crystal growth exclusively from an upper part" is meant the state wherein the crystal growth on the apex or in the apex plane or vicinity of the convex part 11 prevails. In this state, the growth in the concave may occur in the initial stage of growth, but ultimately, the crystal growth in the convex part 11 prevails. In other words, a low dislocation region formed by the lateral growth starting from the upper part as a starting point is effective as conventional ELO that requires a mask. Such growth can be characteristically achieved maskless according to the present invention.

**[0034]** In the embodiments shown in FIG. 6 - FIG. 10, the mask 3, on which the crystal cannot substantially grow, is formed on the concave part 12. By the "on which the crystal cannot substantially grow" is meant a state wherein the crystal growth is difficult to proceed. In this state, the growth on the mask of the concave part may occur in the initial stage of growth, but ultimately, the crystal growth of the convex part 11 prevails.

**[0035]** In other words, low dislocation region formed by the lateral growth from the upper part as a starting point is effective as conventional ELO that requires a mask. The low dislocation density region can be characteristically grown by a single cycle of crystal growth by processing the substrate according to the present invention.

**[0036]** FIG. 1 - 3 and FIG. 6 - 8 are cross sectional views of the convex parts 11 formed to constitute stripes. In FIG. 1 and FIG. 6, substrate 1 having a greater groove depth (convex height) h than a groove width B, as shown in FIG. 1 (a) and FIG. 6 (a), is exemplarily depicted. In this case, a sufficient amount of an ingredient gas does not reach the concave part 12 or the vicinity thereof. In the embodiment shown in FIG. 6, due to the mask 3 applied to the concave part 12, crystal growth occurs only from the upper part of the convex part 11. In FIG. 1 (b) and FIG. 6 (b), 20 is a crystal unit at the start of the crystal growth. Under the circumstances, as the crystal growth proceeds, the films grown in the lateral direction from the upper part of the convex part 11 as the starting point are connected and, as shown in FIG. 1 (c), FIG. 6 (c), the concavo-convex surface of the substrate 1 is covered, leaving cavity 13 in the concave part. In this case, a low dislocation region is formed in the part grown in the lateral direction, or the upper part of the concave part 12, as a result of which the film thus formed has high quality.

**[0037]** According to the method for manufacturing the semiconductor crystal, a semiconductor base of the present invention (a laminate consisting of substrate 1 and semiconductor crystal 2 with cavity 13 between them), as shown in FIG. 1(c), FIG. 2(c), FIG. 6(c) and FIG. 7(c), is manufactured and substrate 1 and semiconductor crystal 2 are separated at a part including cavity parts 13, namely, the convex parts 11 of the substrate, as shown in FIG. 6(d) and FIG. 7(d), to give a desired semiconductor crystal 2 having low dislocation. For the separation, abrading and the like can be typically used but the method is not particularly limited as long as a semiconductor crystal can be taken out.

**[0038]** FIG. 2 shows an embodiment of a substrate 1 where the groove depth (convex height) h is smaller than the groove width B, or groove width B is wider than the width A of the convex part 11 (see FIG. 2(a)). In this case, the ingredient gas reaches the concave part 12 and the vicinity thereof, allowing the growth in the concave part 12. The crystal growth also proceeds from the upper part of the convex part 11, and as shown in FIG. 2(b), crystal units 20, 21 are formed on the upper part of the convex part 11 and the surface of the concave part 12. Under the circumstances, as the crystal growth proceeds, the films grown in the lateral direction from the upper part of the convex part 11 as the starting point are connected and, as shown in FIG. 2(c), the concavo-convex surface of the substrate 1 is covered. In this case, a low dislocation region is formed in the upper part of the concave part 12, as a result of which the film thus formed has high quality.

**[0039]** FIG. 3, FIG. 7(a) - (c) show an embodiment of a substrate 1 where the groove depth (convex height) h is considerably smaller than the groove width B or the groove width B is markedly wider than the width A of the convex part 11 (see FIG. 3(a), FIG. 7(a)).

**[0040]** In the embodiment of FIG. 3, the ingredient gas reaches the concave part 12 and the vicinity thereof, allowing growth in the concave part 12. In the embodiment of FIG. 7, the ingredient gas reaches the mask 3 of the concave part 12 and the vicinity thereof, and there is a possibility that the crystals may grow on the concave part 12. As compared to the growth in the upper part of a convex part, however, the growth rate is extremely slow. This is attributable to the greater proportion of the ingredient material that reached mask 3 but is released again into the gas.

**[0041]** As shown in FIG. 3(b), FIG. 7(b), the crystal growth also proceeds from the upper part of the convex part 11, whereby crystal units 20, 21 are respectively formed on the upper part of the convex part 11 and the surface of the concave part 12. Under the circumstances, as the crystal growth proceeds, the films grown in the lateral direction from the upper part as the starting point are connected and, as shown in FIG. 3(c), FIG. 7(c), the concavo-convex surface of the substrate 1 is covered.

**[0042]** In the embodiment of FIG. 3, a low dislocation region is hardly formed in the part starting from the concave part 12, but a low dislocation region is formed in the part formed the growth in the lateral direction starting from the convex part 11, and the prepared film as a whole has higher quality. In the embodiment of FIG. 7, too, the proportion of the growth in the lateral direction starting from the convex part 11 is grater than in the embodiment of FIG. 1. Therefore, the proportion of low dislocation region is a greater and the prepared film as a whole has higher quality than the embodiment of FIG. 1.

**[0043]** When the concave part is wider and the dislocation extends in the C axis direction, the low dislocation region formed in the upper part of concave part has a greater area. In this case, registration with the emitting part of a light emitting element or with a light receiving part of a light receiving element is easily and conveniently done.

**[0044]** It is also possible to widen the low dislocation region of conventional ELO, but the layer needs to be made thick. A thick layer causes occurrence of camber, making the photolithography step in the process difficult.

**[0045]** According to the present invention, particularly an embodiment wherein a mask is formed in the concave part enables formation of a large low dislocation region on a thin film. As a result, the occurrence of camber can be suppressed, and when a semiconductor element having a large area (e.g., light receiving element etc.) is to be formed, the occurrence of problems caused by camber in a photolithography step can be suppressed. Therefore, an element having improved properties, as compared to conventional ones, in low dark current, high speed of response and the like can be obtained.

**[0046]** According to the manufacturing method of the semiconductor crystal, a laminate is prepared as mentioned above and, substrate 1 and semiconductor crystal 2 are separated as shown in FIG. 7(d) at a part containing cavity 13, or the convex part 11 of the substrate 1, whereby a semiconductor crystal 2 having a desired low dislocation can be obtained.

**[0047]** In the present invention, the convex part 11 is subject to no particular limitation and various shapes can be employed.

**[0048]** To be specific, various combinations where groove depth (convex height) h is greater than the groove width B, groove depth (convex height) h is smaller than the groove width B, groove depth (convex height) h is strikingly smaller than the groove width B, groove width B is strikingly larger than the width A of convex 11 and the like can be employed. Particularly, when the groove depth (convex height) h is greater than the groove width B, the ingredient gas cannot substantially diffuse to the bottom during vapor phase growth, even without a mask on the surface of the concave part, as shown in FIG. 1. Therefore, the ingredient material efficiently contributes to the growth on the upper part of the convex part 11. When the groove width B is greater than the width A of the convex part 11, the region of the growth in the lateral direction becomes larger and a low dislocation region is preferably formed widely.

**[0049]** When the dislocation from the sapphire substrate extends straight, the proportion of the convex part is smaller, wherein a narrower width advantageously results in a smaller number of dislocations. The area occupied by the convex part is preferably not more than 50%, desirably not more than 40%, more desirably not more than 30%. A narrower convex width means a higher effect, which is preferably not more than 5 $\mu$m, desirably not more than 2 $\mu$m, more preferably $0 < \text{convex} < 1$ $\mu$m.

**[0050]** When the convex is narrow, the thickness necessary to make the concave part flat by covering same becomes beneficially smaller. Therefore, the problem of camber caused by the differences in the thermal expansion coefficients can be overcome because of the thin layer that needs to be grown. When the convex is narrow and the area occupied by the convex is small, the above-mentioned effect is joined by an effect of less dislocation and a more superior effect can be achieved. The groove depth (height of convex) is determined from the range capable of affording the effect of the present invention.

**[0051]** For forming such a concavo-convex surface, island type intersperse convex parts, stripe type convex parts consisting of convex lines, lattice convex parts, convex parts, wherein the lines forming these are curves and the like, can be employed.

**[0052]** Of the embodiments of these convex parts, the stripe type forming convex lines is preferable because the manufacturing steps can be simplified and regular patterns can be easily formed. While the longitudinal direction of the stripe is optional, when the material to be grown on a substrate is GaN and the direction is the <1-100> direction of the GaN group material, the diagonal facet, such as the {1-101} plane and the like, is not easily formed, thereby quickening the growth in the lateral direction (lateral growth). Consequently, the concavo-convex surface is covered faster, which is particularly preferable.

**[0053]** When the growth conditions, under which a diagonal facet such as the {1-101} plane and the like is formed, (e.g., low temperature of growth, high $H_2$ concentration etc.), are employed, the dislocation from the substrate first extends straight in the convex part (C axis direction in the case of sapphire C-plane substrate), curves in the facet plane, and may join in the center of the concave part. In this event, a low dislocation region becomes the upper part of the convex part. Thereafter, gas atmosphere, grow temperature and the like are changed to promote the lateral growth, whereby a flat film covering the C-plane can be obtained. When the stripe direction is set to the <11-20> direction, too, the selection of the growth conditions apparently makes a method similar to the above-mentioned method.

**[0054]** The mask 3 to be formed on the concave part 12 needs only to prevent substantial growth thereon, and $SiO_2$, $SiN_x$, $TiO_2$, $ZrO_2$ and the like can be used. It is possible to make a laminate of these materials. According to the manufacturing method of the semiconductor crystal, a mask 3 is formed on the concave part 12. The use of a concavo-convex shaped substrate alone without forming a mask 3 is also acceptable.

**[0055]** As in the Reference Examples shown in FIG. 1 and FIG. 6, when the concavo-convex surface of the substrate 1 is buried leaving the cavity 13, and an emitting part is grown thereon to give a light emitting element, the difference in the refractive index between the cavity and the semiconductor at the interface can be made greater. As a result, a greater proportion of the light headed for the downside of the emitting part is reflected at the interface. For example, when LED is prepared with the sapphire substrate plane placed downside for die bonding, the amount of the light taken out upward preferably increases.

**[0056]** The embedding leaving the cavity 13 reduces the contact area between the substrate 1 and the semiconductor layer to be grown thereon. Thus, the strain produced in the semiconductor, which is caused by difference in lattice constant and thermal expansion coefficient, can be preferably reduced. The reduction of the strain is effective for reducing the camber that occurs when a GaN group material is grown thick on sapphire. Particularly, the conventional methods are associated with the problem of occurrence of camber and cracks due to the difference in thermal expansion coefficients when a GaN group material is crystal grown on an Si substrate, which prevents fine crystal growth. The reduction of the strain by the present invention overcomes this problem.

**[0057]** By utilizing the capability of minimizing the contact area between the substrate 1 and the semiconductor layer 2 grown thereon, the semiconductor layer 2 can be grown thick. As a result, the stress gathers on the small contact part, from where the substrate 1 can be separated from the semiconductor layer 2. By utilizing this effect, substrates of GaN and the like can be prepared.

**[0058]** According to the manufacturing method of the semiconductor crystal, a cavity 13 is formed between the substrate 1 and the semiconductor crystal 2 to minimize the contact area between them, as shown in FIG. 6(c), FIG. 7(c) and FIG. 10. Consequently, the strain caused by differences in lattice constant and thermal expansion coefficient in the semiconductor crystal 2 can be reduced. The reduction of the strain has an effect of reducing the camber that noticeably occurs when a GaN group material as a semiconductor crystal 2 is grown thick on sapphire employed as a substrate 1. Particularly, camber and cracks occur due to the difference in thermal expansion coefficients when a GaN group material is crystal grown on a substrate by a conventional method, which prevents fine crystal growth. This problem can be reduced by the strain reduction effect by the presence of cavity 13.

**[0059]** According to the manufacturing method of the semiconductor crystal, by utilizing the capability of minimizing the contact area between the substrate 1 and the semiconductor layer 2 grown thereon, as mentioned above, when the film is grown to a thickness of not less than 10 $\mu$m, preferably not less than 100 $\mu$m, the stress concentrates to the small contact part, from where the separation of the substrate 1 and the semiconductor layer 2 can be facilitated. In this way, a substrate of GaN and the like can be prepared.

**[0060]** While the above explanation concerns the case where only one layer of semiconductor layer 2 is grown on the substrate 1, a similar step may be repeated to further reduce the dislocation defect. As shown in FIG. 5, FIG. 8 and FIG. 9, after crystal growth of the first semiconductor crystal layer (the first semiconductor layer) 2a to cover the concavo-convex surface of the substrate 1 in the same manner as the above-mentioned, the surface of the first semiconductor layer 2a is processed to have a concavo-convex surface, on which surface a second semiconductor crystal layer (the second semiconductor layer) 2b may be formed by crystal growth by vapor phase growth exclusively from an upper part of the convex part of the first semiconductor layer 2a. In this case, if particularly the convex part 11 of the substrate 1 and the convex part 11a to be formed on the above-mentioned first semiconductor layer 2a are dislocated (namely, by forming a concave cavity part of the first semiconductor layer 2a on a region to which dislocation is propagated from the substrate), the second semiconductor layer 2b is free of propagation of the dislocation. In other words, by this constitution, the entirety of the second semiconductor layer 2b can be a low dislocation region, thereby providing a semiconductor base having a semiconductor crystal layer having a still higher quality. Thereafter, the semiconductor crystal 2 (the second semiconductor layer 2b) is separated from the laminate (semiconductor base) at the cavity 13, as shown in FIG. 10, whereby the necessary semiconductor crystal 2 can be taken out.

**[0061]** It is possible to prevent propagation by forming a mask, such as $SiO_2$ and the like, on the part of the first semiconductor layer, where the dislocation is propagated. That is, the conventionally reported ELO technique may be used for the growth of the second semiconductor layer. In this case, since the first semiconductor layer is formed according to the present invention, there are achieved apparent effects absent in the use of ELO alone, such as thin film, less number of steps and the like.

**[0062]** It is also possible to process the surface of the second semiconductor layer 2b into a concavo-convex surface, on which to form a third semiconductor crystal layer (the third semiconductor layer) by vapor phase growth in the same manner as above. Alternatively, a similar step may be repeated to form plural semiconductor layers in a multiple manner. By this constitution, the dislocation propagated as laminating the layers can be gradually reduced, even without the intentional positional adjustment of the convex part between above and below, as mentioned above, whereby the semiconductor base to be ultimately grown, and the semiconductor crystal separated therefrom, can be made to have a higher quality.

**[0063]** A convex part can be prepared by, for example, forming a pattern according to the shape of the convex part by a conventional photolithography technique, and etching by RIE technique and the like.

**[0064]** A semiconductor layer is preferably formed on a substrate by crystal growth by HVPE, MOCVD, MBE and the like. When a thick film is to be prepared, HVPE is preferable, and a thin film is preferably prepared by MOCVD.

**[0065]** The growth conditions (kind of gas, growth pressure, growth temperature and the like) for crystal growth of the semiconductor layer on a substrate can be determined as necessary according to the object, as long as the effect of the present invention is achieved.

**[0066]** In the following the reference examples 1 and 3 to 13 are not according to the invention but they are useful for understanding the invention.

## Reference Examples

### Reference Example 1

**[0067]** A photoresist was placed to form a pattern (width: 2 μm, period: 4 μm, stripe direction: stripe extending direction being <11-20> direction of sapphire substrate) on a C-plane sapphire substrate. The substrate was etched to form a quadrate shape cross section having a depth of 5 μm with RIE (Reactive Ion Etching) apparatus. The width 2 μm of the aforementioned pattern corresponded to the width of a convex part. Therefore, the width (= period - width of convex) of a concave part was 2 μm, and the aspect ratio (depth/width of concave) then of the concave part cross section was 2.5. After removal of the photoresist, the substrate was set on the MOVPE apparatus. Thereafter, the temperature was raised to 1100°C under a hydrogen atmosphere, and thermal etching was performed. The temperature was lowered to 500°C, and TMG (hereinafter TMG) as a III group ingredient material and ammonia as an N ingredient material were flown, whereby a GaN low temperature buffer layer was grown. The temperature was raised to 1000°C, TMG and ammonia as ingredient materials and silane as a dopant were flown, whereby an n-type GaN layer was grown. The time of growing corresponded to the time necessary for growing GaN in a thickness of 4 μm in a conventional case without concave-convex

**[0068]** The cross section after the growth was observed. As a result, the concave part of the substrate showed some trace of growth, but, as shown in FIG. 1(c), the concavo-convex was covered leaving the cavity 13 in the concave part, whereby a flat GaN film was obtained.

**[0069]** For comparison, a GaN layer formed on a conventional C-plane sapphire substrate under the same growth conditions and a GaN film ELO grown using an $SiO_2$ mask having the same pattern (conventional ELO sample by the mask method) were prepared.

**[0070]** For evaluation, InGaN (InN mixed crystal ratio= 0.2, 100 nm thickness) was continuously grown and the pits (corresponding to dislocation) appeared thereon were counted and taken as dislocation density. The carrier density was evaluated by Hall effect measurement, and fluctuation of the crystal axis was evaluated by ¢ scan of XRC. The evaluation results are shown in Table 1, FIG. 4.

Table 1

| sample | dislocation density | carrier density | FWHM of XRC |
|---|---|---|---|
| Example sample | $4\times10^7$ cm$^{-2}$ | $1\times10^{16}$ cm$^{-3}$ | 170 sec |
| Conventional ELO sample | $4\times10^7$ cm$^{-2}$ | $5\times10^{17}$ cm$^{-3}$ | 200-400 sec |
| Normal GaN | $2\times10^9$ cm$^{-2}$ | $1\times10^{16}$ cm$^{-3}$ | 220 sec |

**[0071]** The Example sample showed reduction of dislocation density to the same level as the level of conventional ELO. On the other hand, the carrier concentration was of the same level as normal GaN growth. FWHM of XRC was the smallest and 170 sec. As an overall evaluation, the film had high quality.

**[0072]** It was also confirmed from XRC ¢ scan data of FIG. 4 that the crystal had a high quality without fluctuation of the crystal axis intensified near the lateral growth direction, like the GaN film prepared by ELO growth using an $SiO_2$ mask.

## Example 2

**[0073]** This Example followed Reference Example 1 except the shape of the concavo-convex part, which was changed to the following. (width: 2 μm, period:4 μm, stripe direction: <11-20> of sapphire substrate) The substrate was etched to form a quadrate shape cross section having a depth of 1 μm with RIE (Reactive Ion Etching) apparatus. The aspect ratio then was 0.25.

**[0074]** The cross section after the growth was observed. As a result, the concavo-convex part was buried and the part corresponding to the concave part 12 was substituted by the cavity 13 and the GaN film 21 on the bottom thereof, as shown in FIG. 2(c).

**[0075]** For evaluation of this film, InGaN (InN mixed crystal ratio= 0.2, 100 nm thickness) was continuously grown and the pits appeared thereon as mentioned above were observed. As a result, many pits corresponding to the dislocation were observed in the upper part of the convex part, but the pits seen in the part grown in the lateral direction from the upper part of the convex part as a starting point were small in number, wherein the dislocation density was $4 \times 10^7$ cm$^{-2}$ as in Reference Example 1.

## Reference Example 3

**[0076]** This Example followed Reference Example 1 except the shape of the concavo-convex part, which was changed to the following and the layer grown on the concavo-convex part had a thickness of 1 μm. (width: 0.5 μm, period: 1 μm, stripe direction: <11-20> of sapphire substrate). The substrate was etched to form a quadrate shape cross section having a depth of 1.0 μm with RIE apparatus.

**[0077]** The cross section after the growth was observed. As a result, the concavo-convex part was buried and the surface was flat. By shortening the width and period, a film already having a flat surface at a thickness of 1 μm can be obtained. For evaluation of this film, InGaN (InN mixed crystal ratio= 0.2, 100 nm thickness) was continuously grown and the pits were observed as in the above Examples. Many pits corresponding to dislocation appeared in the upper part of the convex part but the pits seen in the part grown in the lateral direction from the upper part of the convex part as a starting point were small in number, wherein the dislocation density was $4 \times 10^7$ cm$^{-2}$ as in Reference Example 1.

## Reference Example 4

**[0078]** This Example followed Reference Example 1 except the shape of the concavo-convex part, which was changed to the following. (width: 0.3 μm, period: 3 μm, stripe direction: <11-20> of sapphire substrate) The substrate was etched to form a quadrate shape cross section having a depth of 3.0 μm with RIE apparatus.

**[0079]** The cross section after the growth was observed. As a result, the concavo-convex part was buried and the outermost surface was flat. For evaluation of this film, InGaN (InN mixed crystal ratio= 0.2, 100 nm thickness) was continuously grown and the pits appeared were observed as mentioned above.

**[0080]** Pits corresponding to dislocation appeared in the upper part of the convex part but the number was markedly smaller. The pits seen in the part grown in the lateral direction from the upper part of the convex part as a starting point were small in number. On the other hand, some pits were found in the center of the concave part. The dislocation density of this film was $2 \times 10^6$ cm$^{-2}$, showing considerable decrease as compared to Reference Example 1 and Example 2 and conventional GaN growth. This is considered to be attributable to the reduced area occupied by the convex part and the reduced number of dislocation propagated.

## Reference Example 5

**[0081]** An n-type AlGaN clad layer, an InGaN light emitting layer, a p-type AlGaN clad layer and a p-type GaN contact layer were successively formed on the film obtained in Reference Example 1 to give an ultraviolet LED wafer having a light emission wavelength of 370 nm.

**[0082]** Thereafter, an electrode was formed and divided into elements to give LED elements. The average output and reverse current property of the LED chips obtained from the whole wafer were evaluated. The comparison objects were ultraviolet LED chip having the above-mentioned structure formed using a conventional ELO technique and an ultraviolet LED chip having the above-mentioned structure formed by the conventional sapphire substrate. The evaluation results of these are shown in Table 2.

Table 2

| sample | Output (20 mA) | current leaked by application of -10V |
|---|---|---|
| Example sample | 1.7 mW | 10 nA |
| conventional ELO sample | 1.5 mW | 50 nA |
| normal GaN | 0.9 mW | 1 μA |

**[0083]** As is shown in Table 2, the sample prepared according to the present invention showed higher output than the conventional samples, and it was found that a high quality LED associated with less current leakage could be prepared.

**Reference Example 6**

**[0084]** This Example followed Reference Example 1 except trimethyl aluminum (TMA) was added during the growth of a semiconductor layer.

**[0085]** As a result, an AlGaN (AL composition 0.2) film left a cavity in the concave part and the film covering the concavo-convex part was grown flat. The pits appeared in the part grown in the lateral direction starting from the upper part of the convex part as a starting point was small in number. Consequently, an AlGaN film having high quality (low dislocation density), that could not be afforded by a conventional ELO technique, was confirmed to have been achieved by the present invention.

**Reference Example 7**

**[0086]** In the next example, GaN was used as a substrate. A photoresist was placed to form a pattern on a GaN substrate (width: 2 μm, period:4 μm, stripe direction: < 1-100> of GaN substrate), and the substrate was etched to form a quadrate shape cross section having a depth of 5 μm with RIE apparatus. The aspect ratio then was 2.5. After removal of the photoresist, the substrate was set on the MOVPE apparatus. Thereafter, the temperature was raised to 1000°C under an atmosphere of a nitrogen, hydrogen and ammonia mixture. Then, TMG and ammonia as ingredient materials and silane as dopant were flown, whereby an n-type GaN layer was grown. The time of growing then corresponded to the time necessary for growing GaN in a thickness of 4 μm in a conventional case without concavo-convex.

**[0087]** The cross section after the growth was observed. As a result, the growth in the substrate concave part and the growth on the side surface of the convex part were found but, as shown in FIG. 5, the concavo-convex part was covered leaving the cavity, whereby a flat GaN film was obtained. Then, the pits in the obtained film were evaluated. GaN used as a substrate had a pit density of $2 \times 10^5$ $cm^{-2}$. By the growth of this Example, the pits decreased to $1 \times 10^5$ $cm^{-2}$ in the upper part of the convex and $5 \times 10^3$ $cm^{-2}$ in the upper part of the concave part. It was confirmed that a dislocation density reduction effect was present in a substrate having already less dislocation.

**Reference Example 8**

**[0088]** Using the GaN crystal prepared in Reference Example 1 was used as a first semiconductor layer, a second semiconductor layer was grown thereon. First, a photoresist was placed to form a pattern (width: 2 μm, period:4 μm, stripe direction: < 1-100> of GaN substrate) on a GaN crystal (the first semiconductor layer) and the substrate was etched to form a quadrate shape cross section having a depth of 2 μm with RIE apparatus. The formation of the pattern included registering the concave part of the first semiconductor layer to the substrate convex part. The aspect ratio then was 1. After removal of the photoresist, the substrate was set on the MOVPE apparatus. Thereafter, the temperature was raised to 1000°C under an atmosphere of a nitrogen, hydrogen and ammonia mixture. Then, TMG and ammonia as ingredient materials and silane as a dopant were flown, whereby an n-type GaN layer was grown. The time of growing then corresponded to the time necessary for growing GaN in a thickness of 4 μm in a conventional case without concavo-convex.

**[0089]** The cross section after the growth was observed. As a result, the growth in the substrate concave part and the growth on the side surface of the convex part were found, but the concavo-convex part was covered leaving the cavity, and a flat GaN film was obtained. Subsequently, the pits in the obtained film were evaluated to find a decrease to $8 \times 10^5$ $cm^{-2}$ in number. By repeating this Example, a further effect on the reduction of dislocation density was confirmed to be achieved.

**Reference Example 9**

**[0090]** A photoresist was placed to form a pattern on a C-plane sapphire substrate (width: 2 μm, period: 6 μm, stripe direction: stripe extending direction being <11-20> direction of sapphire substrate), and the substrate was etched to form a quadrate shape cross section having a depth of 2 μm with RIE apparatus. An $SiO_2$ film was deposited on the entirety of the substrate in a thickness of 0.1 μm, and the photoresist and the $SiO_2$ film deposited thereon were removed by a lift-off step. In this way, a mask layer was formed on the substrate concave part. Thereafter, the substrate was set on an MOVPE apparatus, the temperature was raised to 1100°C under a hydrogen atmosphere to apply and thermal etching. Then, the temperature was lowered to 500°C, and TMG as a III group ingredient material and ammonia as an N ingredient material were flown, whereby a GaN low temperature buffer layer was grown. The temperature was raised to 1000°C, and TMG and ammonia as ingredient materials and silane as a dopant were flown, whereby an n-type GaN layer was grown on the substrate. The time of growing then corresponded to the time necessary for growing GaN in a thickness of 4 μm in a conventional case without concavo-convex.

**[0091]** After the growth, the cross section was observed. As a result, the mask on the substrate concave part showed some trace of growth but, as shown in FIG. 7(c), the concavo-convex part was covered leaving the cavity 13 in the concave part, whereby a flat GaN film was obtained. For comparison, similar study was done by a conventional ELO method. An $SiO_2$ mask (i.e., mask width 4 μm, period 6 μm) corresponding to the width and period of the concavo-convex of this Example was formed and grown for a period corresponding to the time necessary for growing normal GaN in a thickness of 4 μm. The cross section of the obtained sample was observed. As a result, growth in the lateral direction occurred on the $SiO_2$ mask, and though the junction was observed, the surface had not become flat yet. The growth time necessary for making the surface flat was examined, and found to be the time corresponding to the time necessary for growing GaN in a thickness of 10 μm by conventional GaN growth. In this case, while the surface of the crystal layer was flat, the obtained wafer showed considerable camber as a result of thickening of the film.

**[0092]** As is evident from the comparison in this Example, the use of the present invention affords a thin and flat film surface even if the concave part to be subjected to lateral growth is wide.

**Reference Example 10**

**[0093]** GaN was used as a substrate in the next example. A photoresist was placed to form a pattern on a GaN substrate (width: 2 μm, period: 6 μm, stripe direction: <1-100> of GaN substrate), and the substrate was etched to form a quadrate shape cross section having a depth of 2 μm with RIE apparatus. An $SiO_2$ film was deposited on the entirety of the substrate in a thickness of 0.1 μm, and the photoresist and the $SiO_2$ film deposited thereon were removed by a lift-off step. The GaN substrate thus processed was set on an MOVPE apparatus, and the temperature was raised to 1000°C under an atmosphere of a nitrogen, hydrogen and ammonia mixture. Then TMG and ammonia as ingredient materials and silane as a dopant were flown, whereby an n-type GaN layer was grown. The time of growing then corresponded to the time necessary for growing GaN in a thickness of 4 μm in a conventional case without concavo-convex.

**[0094]** After the growth, the cross section was observed. As a result, the mask on the concave part of the substrate showed some trace of growth and growth in the side surface of the convex part, but, as shown in FIG. 8, the concavo-convex was covered leaving the cavity part, whereby a flat GaN film was obtained. Then, the pits of the obtained film were evaluated. GaN used as a substrate had a pit density of $2 \times 10^5$ $cm^{-2}$. By the growth of this Example, the pits decreased to $1 \times 10^5$ $cm^{-2}$ in the upper part of the convex part and $5 \times 10^3$ $cm^{-2}$ in the upper part of the concave part. It was confirmed that a dislocation density reduction effect is achieved on a substrate having already less dislocation.

**Reference Example 11**

**[0095]** Using the GaN crystal prepared in Reference Example 9 as a first semiconductor layer, a second semiconductor layer was grown thereon. First, a photoresist was placed to form a pattern (width: 2 μm, period: 6 μm, stripe direction: < 1-100> of GaN substrate) on a GaN crystal (the first semiconductor layer) and the substrate was etched to form a quadrate shape cross section having a depth of 2 μm with RIE appartus. The formation of the pattern included registering the concave part of the first semiconductor layer to the substrate convex part. An $SiO_2$ film was deposited on the entirety of the substrate in a thickness of 0.1 μm, and the photoresist and the $SiO_2$ film deposited thereon were removed by a lift-off step. Thereafter, the substrate was set on an MOVPE apparatus, the temperature was raised to 1000°C under an atmosphere of a nitrogen, hydrogen and ammonia mixture. Then, TMG and ammonia as ingredient materials and silane as a dopant were flown, whereby an n-type GaN layer was grown. The time of growing then corresponded to the time necessary for growing GaN in a thickness of 4 μm in a conventional case without concavo-convex.

**[0096]** Then, the pits of the obtained film were evaluated. As a result, the pits decreased to $8 \times 10^5$ $cm^{-2}$. By repeating this Example, a further effect of the reduction of dislocation density was confirmed to be achieved.

**[0097]** In this Example, a $SiO_2$ film was formed on the concave part of the first semiconductor layer. Even if a $SiO_2$ film was not formed, by making the thickness of the second semiconductor layer 6 μm, similar results were obtained.

### Reference Example 12

**[0098]** In the same manner as in the above-mentioned Reference Example 9, a mask layer was formed on the concave part of a substrate, a GaN low temperature buffer layer was grown, the temperature was raised to 1000°C, and TMG and ammonia as ingredient materials and silane as a dopant were flown for 10 h to grow an n-type GaN layer in the thickness of 30 μm.

**[0099]** The obtained GaN crystal was observed. As a result, camber slightly occurred but the crystal was free of cracks or breakage, and the obtained was a mirror plane. The cross section after the growth was observed. As a result, the mask on the concave part of the substrate showed some trace of growth, but, as shown in FIG. 7(c), the concavo-convex of the substrate was covered leaving the cavity 13 in the concave part, whereby a flat GaN crystal was obtained.

### Comparative Examples 1, 2

**[0100]** For comparison, a GaN layer formed on a conventional C-plane sapphire substrate under the same growth conditions (Comparative Example 1), and a GaN film ELO grown using an $SiO_2$ mask having the same pattern (Comparative Example 2) were prepared.

**[0101]** After the growth, the samples were taken out from the apparatuses. The sample grown without any treatment was found to have been broken into small pieces with a number of cracks. The ELO grown sample was free of breakage but contained considerable cambers and a number of cracks.

**[0102]** The GaN crystal obtained in Reference Example 12 and the GaN crystal obtained by ELO growth in Comparative Example 2 were separated from the substrate. The GaN crystal surface was fixed with a wax with the surface downside. Thereafter, the sapphire substrate was removed by abrasion.

**[0103]** The GaN crystal obtained by ELO growth in Comparative Example 2 was incapable of uniform abrasion due to the considerable camber. After the abrasion, the GaN crystal was released from the wax. The sample prepared in Reference Example 1 permitted taking out of the GaN crystal, but the GaN crystal sample ELO grown in Comparative Example 2 broke into pieces.

### Reference Example 13

**[0104]** As shown in FIG. 10, the GaN crystal free of the separation from the sapphire substrate, as obtained in Examples 12, was used as the first semiconductor layer 2a, and the second semiconductor layer 2 was grown thereon. First, a photoresist was placed to form a pattern on the GaN first semiconductor layer (width: 2 μm, period: 6 μm, stripe direction: <1-100> direction of GaN substrate), and the substrate was etched to form a quadrate shape cross section having a depth of 2 μm with RIE apparatus. The formation of the pattern here included making the part of the first semiconductor layer, where dislocation was frequent, a concave part. An $SiO_2$ film was deposited on the entirety of the substrate in a thickness of 0.1 μm, and the photoresist and the $SiO_2$ film deposited thereon were removed by a lift-off step. Thereafter, the substrate was set on an MOVPE apparatus, and the temperature was raised to 1000°C under an atmosphere of a nitrogen, hydrogen and ammonia mixture. The TMG and ammonia as ingredient materials and silane as a dopant were flowm, whereby an n-type GaN layer was grown. The time of growing then corresponded to the time necessary for the growth of 4 μm thickness of GaN grown in a conventional case without concavo-convex. The sample was placed in an HVPE apparatus for growing, thereby affording a GaN crystal having a total film thickness of 200 μm.

**[0105]** In the same manner as in Reference Example 12, the sapphire substrate was removed by abrasion to give a GaN crystal. After the growth, the pits in the surface were evaluated. As a result, the pits decreased to $8 \times 10^5$ $cm^{-2}$. By repeating this Example, it was confirmed that a high quality GaN crystal having a low dislocation could be obtained.

### Industrial Applicability

**[0106]** According to the semiconductor base and the manufacturing method therefor of the present invention as described above, by forming a convex part on a substrate, lateral growth capable of forming a low dislocation region on a part other than a mask layer, can be achieved. Therefore, problems caused by formation of a mask layer can be solved, such as occurrence of new defects in the junction part of the part formed by lateral growth, due to the micro tilting of the axis, autodoping problem, unattainable selective growth of Al-containing semiconductor materials and the like. After forming a concavo-convex surface on a substrate, moreover, the growth of a buffer layer to the growth of a semiconductor crystal layer, such as light emitting part etc., can be achieved sequentially by a single cycle of growth, which advantageously simplifies the production process.

**[0107]** Combined with improved reflectivity by the use of cavity and a phenomenon of a residual strain and the like, the present invention is highly valuable for the improvement of properties and low costs. Particularly, when the bottom of the concave part is covered with a mask, the growth in the concave part can be suppressed, thereby increasing the efficiency of lateral growth.

**[0108]** According to the manufacturing method of the semiconductor crystal of the present invention, a semiconductor crystal layer having a large area can be realized by the effect of suppression of the residual strain and the like, because the contact area between the substrate and the crystal growth layer is small. Therefore, the present invention achieves growth of a large area, which is not affordable by conventional growth or thick film growth by ELO forming a mask layer. In addition, it solves the problems of occurrence of new defects in the junction part of the part formed by lateral growth, due to the micro tilting of the axis, and autodoping problem. The present invention provides extremely useful effects of a semiconductor crystal having a large area, improvement of properties and low costs.

## Claims

1. A semiconductor base comprising a single material substrate and a layer of semiconductor crystal formed on said substrate by vapor phase growth, wherein
a crystal growth plane of the substrate is processed by etching to give a concavo-convex surface,
the semiconductor crystal is a GaN group semiconductor crystal defined by $Al_x Ga_{1-x-y} In_yN$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$) which is grown from an upper part of the convex part of the concavo-convex surface and the concave part of the concavo-convex surface, and
the semiconductor crystals grown in the lateral direction from the upper part of the convex part are joined to cover said concavo-convex surface while leaving a cavity between the layer and the semiconductor crystal grown from the concave part.

2. The semiconductor base of claim 1, wherein the GaN group semiconductor crystal is GaN,

3. The semiconductor base of claim 1 or 2, wherein the substrate is made of sapphire (C-plane, A-plane, R-plane), SiC (6H, 4H, 3C), GaN, Si, Spinel, ZnO, GaAs or NGO.

4. The semiconductor base of any of claims 1 - 3, wherein the GaN group semiconductor crystal is grown via a buffer layer.

5. The semiconductor base of claim 4, wherein the buffer layer is a GaN low temperature buffer layer.

6. The semiconductor base of any of claims 1 - 5, wherein the convex part of the concavo-convex surface of the substrate is an island type intersperse convex part, a stripe type convex part consisting of convex lines, a lattice convex part, or any of these convex parts formed by curves.

7. The semiconductor base of any of claims 1 - 5, wherein the convex parts of the concavo-convex surface of the substrate form parallel stripes, and the longitudinal direction of the stripe is the <1-100> direction of the GaN group semiconductor crystal, or the <11-20> direction thereof.

8. The semiconductor base of claim 7, wherein the convex part has a width of not more than 5 μm.

9. The semiconductor base of any of claims 1 - 8, wherein the area of the convex part of the concavo-convex surface of the substrate is not more than 50%.

10. The semiconductor base of any of claims 1 - 9, wherein the layer of the semiconductor crystal is used as the first semiconductor crystal layer, the surface of the first semiconductor crystal layer is processed to have a concavo-convex surface, and plural semiconductor crystal layers are formed in multiplicity on the concavo-convex surface by repeating a growth step similar to the growth step of the first semiconductor crystal layer.

11. A method for manufacturing a semiconductor base comprising a single material substrate and a semiconductor crystal formed on said substrate which is a GaN group semiconductor crystal defined by $Al_x Ga_{1-x-y} In_yN$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$), which method comprises
preparing a single material substrate having a concavo-convex surface formed by etching,
supplying an ingredient gas to the substrate to grow, by vapor phase, crystals from the upper part of the convex

part of the concavo-convex surface and the concave part of the concavo-convex surface, and joining the semiconductor crystal grown in the lateral direction from the upper part of said convex part thereby covering said concavo-convex surface with the joined crystal in such a manner that a cavity is formed between the joined crystal and the crystal grown from the concave part.

**12.** The method of claim 11, wherein
the layer of the semiconductor crystal is used as the first semiconductor crystal layer, the surface of the first semiconductor crystal layer is processed to have a concavo-convex surface, and plural semiconductor crystal layers are formed in multiplicity on the concavo-convex surface by repeating a growth step similar to the growth step of the first semiconductor crystal layer.

**13.** A method for manufacturing a semiconductor crystal, which method comprises
preparing a semiconductor base of any of claims 1 - 10, and
separating the semiconductor crystal from the substrate at a cavity formed between the semiconductor crystal layer and the concave part, to remove the semiconductor crystal layer.

**Patentansprüche**

**1.** Halbleiterbasis, die ein Substrat aus einem einzigen Material und eine durch Kristallwachstum aus der Dampfphase auf dem Substrat gebildete Schicht aus Halbleiterkristall umfasst;
wobei
eine Kristallwachstumsebene des Substrats durch Ätzen unter Bildung einer konkav-konvexen Fläche verarbeitet wird;
der Halbleiterkristall ein Halbleiterkristall der GaN-Gruppe ist, der durch $Al_xGa_{1-x-y}In_yN$ ($0 \leq x \leq 1$; $0 \leq y \leq 1$) definiert ist und ausgehend von einem oberen Teil des konvexen Teils der konkav-konvexen Fläche und dem konkaven Teil der konkav-konvexen Fläche wachsen gelassen wird; und
die Halbleiterkristalle, die in seitlicher Richtung ausgehend vom oberen Teil des konvexen Teils gewachsen sind, so miteinander verbunden werden, dass sie die konkav-konvexe Fläche bedecken, während sie zwischen der Schicht und dem ausgehend vom konkaven Teil gewachsenen Halbleiterkristall einen Hohlraum frei lassen.

**2.** Halbleiterbasis gemäß Anspruch 1, wobei es sich bei dem Halbleiterkristall der GaN-Gruppe um GaN handelt.

**3.** Halbleiterbasis gemäß Anspruch 1 oder 2, wobei das Substrat aus Saphir (C-Ebene, A-Ebene, R-Ebene), SiC (6H, 4H, 3C), GaN, Si, Spinell, ZnO, GaAs oder NGO besteht.

**4.** Halbleiterbasis gemäß einem der Ansprüche 1 bis 3, wobei der Halbleiterkristall der GaN-Gruppe über eine Pufferschicht wachsen gelassen wird.

**5.** Halbleiterbasis gemäß Anspruch 4, wobei die Pufferschicht eine GaN-Niedertemperaturpufferschicht ist.

**6.** Halbleiterbasis gemäß einem der Ansprüche 1 bis 5, wobei es sich bei dem konvexen Teil der konkav-konvexen Fläche des Substrats um einen eingestreuten konvexen Teil des Inseltyps, einen konvexen Teil des Streifentyps, der aus konvexen Linien besteht, einen konvexen Gitterteil oder irgendeinen dieser konvexen Teile, der durch gekrümmte Linien gebildet ist, handelt.

**7.** Halbleiterbasis gemäß einem der Ansprüche 1 bis 5, wobei die konvexen Teile der konkav-konvexen Fläche des Substrats parallele Streifen bilden und die Längsrichtung des Streifens der <1-100>-Richtung des Halbleiterkristalls der GaN-Gruppe oder der <11-20>-Richtung desselben entspricht.

**8.** Halbleiterbasis gemäß Anspruch 7, wobei der konvexe Teil eine Breite von nicht mehr als 5 $\mu$m hat.

**9.** Halbleiterbasis gemäß einem der Ansprüche 1 bis 8, wobei der Flächenanteil des konvexen Teils der konkav-konvexen Fläche des Substrats nicht größer als 50% ist.

**10.** Halbleiterbasis gemäß einem der Ansprüche 1 bis 9, wobei die Schicht des Halbleiterkristalls als erste Halbleiterkristallschicht verwendet wird, die Oberfläche der ersten Halbleiterkristallschicht so verarbeitet wird, dass sie eine konkav-konvexe Fläche aufweist, und mehrere Halbleiterkristallschichten in Vielzahl auf der konkav-konvexen Fläche gebildet werden, indem man einen Wachstumsschritt, der dem Wachstumsschritt der ersten Halbleiterkristallschicht gleicht, wiederholt.

**11.** Verfahren zur Herstellung einer Halbleiterbasis, die ein Substrat aus einem einzigen Material und einen auf dem Substrat gebildeten Halbleiterkristall umfasst, bei dem es sich um einen Halbleiterkristall der GaN-Gruppe handelt, der durch $Al_xGa_{1-x-y}In_yN$ ($0 \leq x \leq 1$; $0 \leq y \leq 1$) definiert ist, wobei das Verfahren Folgendes umfasst:

Herstellen eines Substrat aus einem einzigen Material, das eine durch Ätzen gebildete konkav-konvexe Fläche aufweist;
Zuführen eines Komponentengases zu dem Substrat zum Wachsenlassen von Kristallen aus der Dampfphase ausgehend vom oberen Teil des konvexen Teils der konkav-konvexen Fläche und dem konkaven Teil der konkav-konvexen Fläche und Verbinden des Halbleiterkristalls, der in seitlicher Richtung ausgehend vom oberen Teil des konvexen Teils gewachsen ist, wodurch die konkav-konvexe Fläche in einer solchen Weise mit dem verbundenen Kristall bedeckt wird, dass zwischen dem verbundenen Kristall und dem ausgehend vom konkaven Teil gewachsenen Kristall ein Hohlraum entsteht.

**12.** Verfahren gemäß Anspruch 11, wobei die Schicht des Halbleiterkristalls als erste Halbleiterkristallschicht verwendet wird, die Oberfläche der ersten Halbleiterkristallschicht so verarbeitet wird, dass sie eine konkav-konvexe Fläche aufweist, und mehrere Halbleiterkristallschichten in Vielzahl auf der konkav-konvexen Fläche gebildet werden, indem man einen Wachstumsschritt, der dem Wachstumsschritt der ersten Halbleiterkristallschicht gleicht, wiederholt.

**13.** Verfahren zur Herstellung eines Halbleiterkristalls, wobei das Verfahren Folgendes umfasst:

Herstellen einer Halbleiterbasis gemäß einem der Ansprüche 1 bis 10; und
Abtrennen des Halbleiterkristalls von dem Substrat an einem zwischen der Halbleiterkristallschicht und dem konkaven Teil gebildeten Hohlraum unter Entfernen der Halbleiterkristallschicht.

## Revendications

**1.** Base de semi-conducteur comprenant un substrat à matériau unique et une couche de cristal semi-conducteur formée sur ledit substrat par croissance en phase vapeur, dans laquelle

■ un plan du substrat pour la croissance du cristal est traité par gravure pour donner une surface concavo-convexe,
■ le cristal semi-conducteur est un cristal semi-conducteur appartenant au groupe GaN défini par $Al_x Ga_{1-x-y} In_yN$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$) dont la croissance a été réalisée à partir d'une partie supérieure de la partie convexe de la surface concavo-convexe et de la partie concave de la surface concavo-convexe, et
■ les cristaux semi-conducteurs dont la croissance a été réalisée dans le sens latéral à partir de la partie supérieure de la partie convexe sont joints pour recouvrir ladite surface concavo-convexe tout en laissant une cavité entre la couche et le cristal semi-conducteur dont la croissance a été réalisée à partir de la partie concave.

**2.** Base de semi-conducteur selon la revendication 1, dans laquelle le cristal semi-conducteur appartient au groupe GaN est GaN.

**3.** Base de semi-conducteur selon la revendication 1 ou 2, dans laquelle le substrat est composé de saphir (plan C, plan A, plan R), de SiC (6H, 4H, 3C), de GaN, de Si, de spinelle, de ZnO, de GaAs ou de NGO.

**4.** Base de semi-conducteur selon l'une quelconque des revendications 1 à 3, dans laquelle la croissance du cristal semi-conducteur appartenant au groupe GaN est réalisée par l'intermédiaire d'une couche tampon.

**5.** Base de semi-conducteur selon la revendication 4, dans laquelle la couche tampon est une couche tampon basse température à base de GaN.

**6.** Base de semi-conducteur selon l'une quelconque des revendications 1 à 5, dans laquelle la partie convexe de la surface concavo-convexe du substrat est une partie convexe dispersée de type îlot, une partie convexe de type bande consistant en des lignes convexes, une partie convexe en réseau, ou l'une quelconque de ces parties convexes qui est formée par des courbes.

**7.** Base de semi-conducteur selon l'une quelconque des revendications 1 à 5, les parties convexes de la surface concavo-convexe du substrat forment des bandes parallèles, et la direction longitudinale de la bande est la direction <1-100> du cristal semi-conducteur appartenant au groupe GaN, ou la direction <11-20> de celui-ci.

**8.** Base de semi-conducteur selon la revendication 7, dans laquelle la partie convexe possède une largeur d'au plus 5 $\mu$m.

**9.** Base de semi-conducteur selon l'une quelconque des revendications 1 à 8, dans laquelle la superficie de la partie convexe de la surface concavo-convexe du substrat est d'au plus 50 %.

**10.** Base de semi-conducteur selon l'une quelconque des revendications 1 à 9, dans laquelle la couche de cristal semi-conducteur est utilisée en tant que première couche de cristal semi-conducteur, la surface de la première couche de cristal semi-conducteur est traitée de manière à avoir une surface concavo-convexe, et de multiples couches de cristal semi-conducteur sont formées sur la surface concavo-convexe en répétant une étape de croissance semblable à l'étape de croissance de la première couche de cristal semi-conducteur.

**11.** Méthode de fabrication d'une base de semi-conducteur comprenant un substrat à matériau unique et un cristal semi-conducteur formé sur ledit substrat qui est un cristal semi-conducteur appartenant au groupe GaN défini par $Al_x Ga_{1-x-y} In_yN$ ($0 \leq x \leq 1$, $0 \leq y \leq 1$), ladite méthode comprenant

- la préparation d'un substrat à matériau unique possédant une surface concavo-convexe formée par gravure,
- la fourniture d'un ingrédient gazeux au substrat pour réaliser la croissance, en phase vapeur, de cristaux à partir de la partie supérieure de la partie convexe de la surface concavo-convexe et de la partie concave de la surface concavo-convexe, et le raccordement du cristal semi-conducteur dont la croissance a été réalisée dans le sens latéral à partir de la partie supérieure de ladite partie convexe pour ainsi recouvrir ladite surface concavo-convexe avec le cristal joint de manière à ce qu'une cavité soit formée entre le cristal joint et le cristal dont la croissance a été réalisée à partir de la partie concave.

**12.** Méthode selon la revendication 11, dans laquelle la couche de cristal semi-conducteur est utilisée en tant que première couche de cristal semi-conducteur, la surface de la première couche de cristal semi-conducteur est traitée de manière à avoir une surface concavo-convexe, et de multiples couches de cristal semi-conducteur sont formées sur la surface concavo-convexe en répétant une étape de croissance semblable à l'étape de croissance de la première couche de cristal semi-conducteur.

**13.** Méthode de fabrication d'un cristal semi-conducteur, ladite méthode comprenant

- la préparation d'une base de semi-conducteur selon l'une quelconque des revendications 1 à 10, et
- la séparation du cristal semi-conducteur du substrat au niveau d'une cavité formée entre la couche de cristal semi-conducteur et la partie concave, pour retirer la couche de cristal semi-conducteur.

FIG. 1

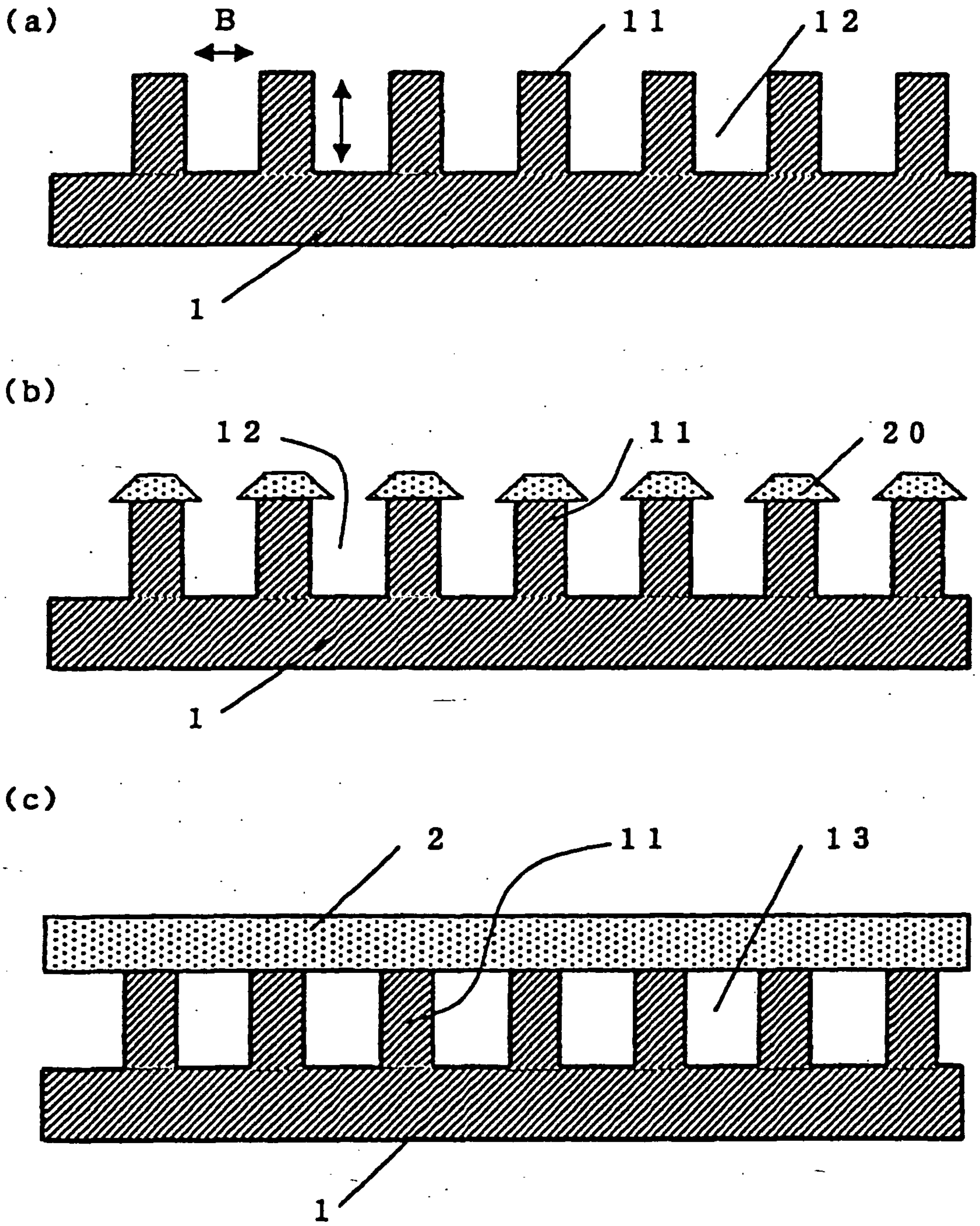


FIG. 2

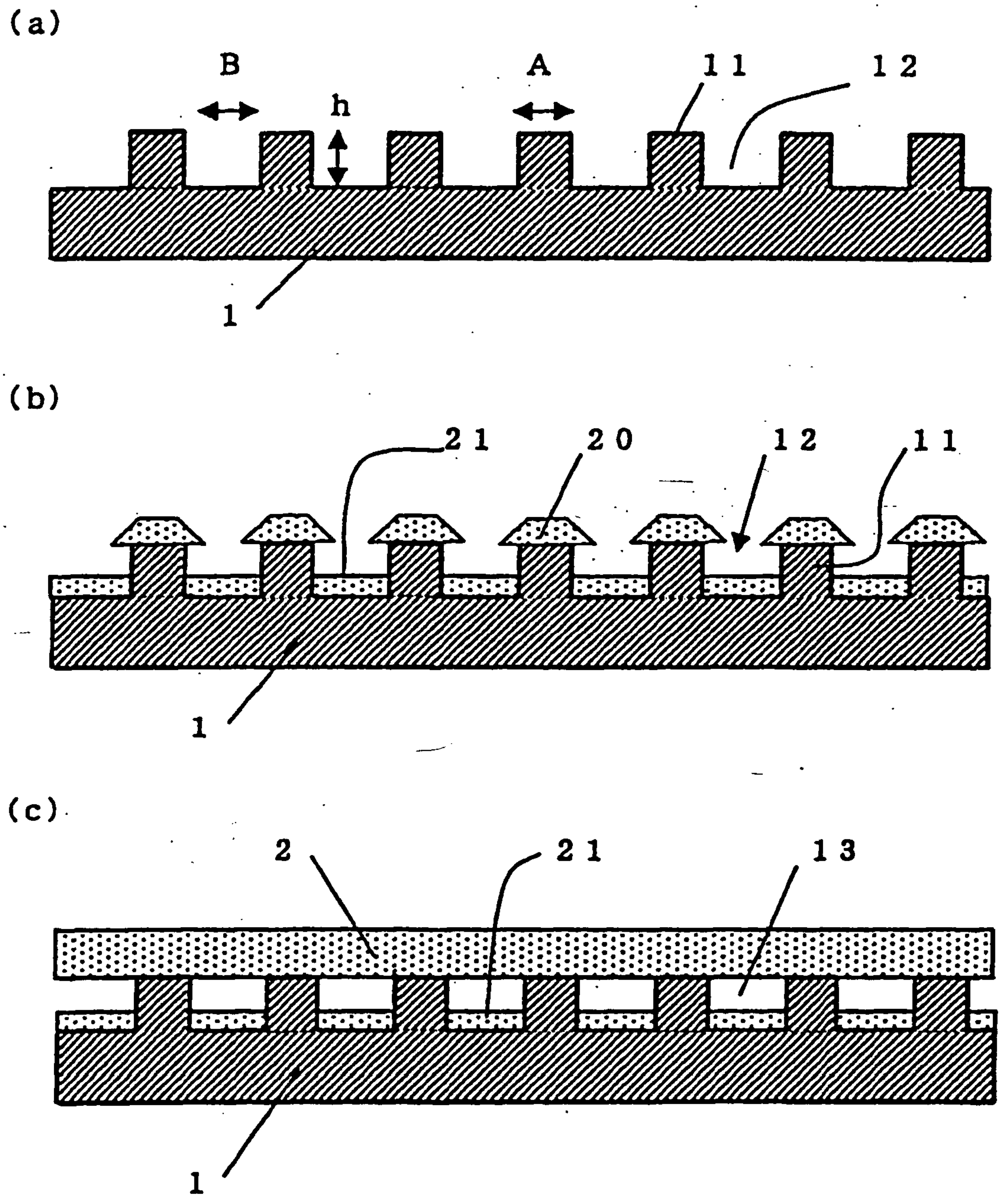


FIG. 3

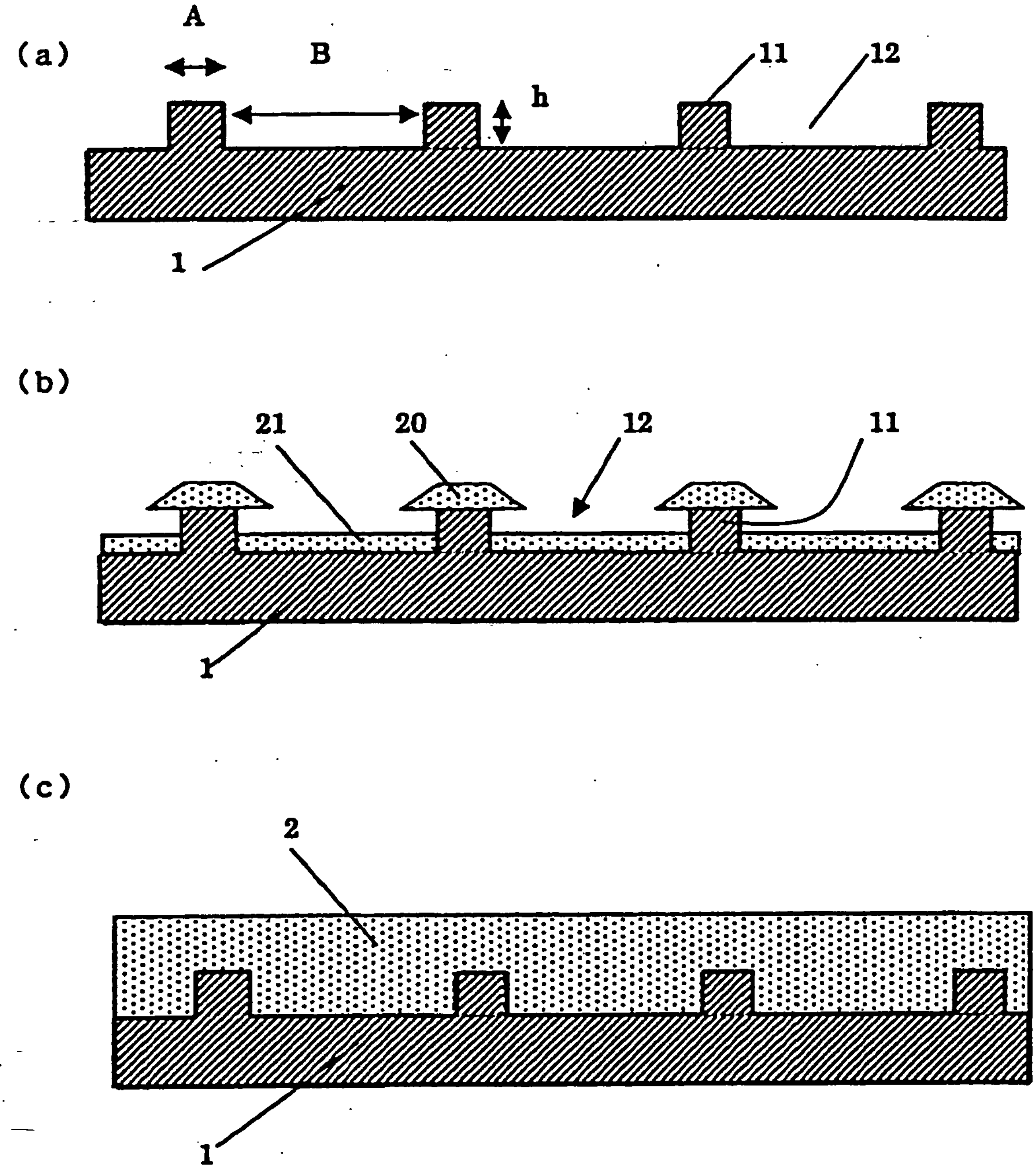


FIG. 4

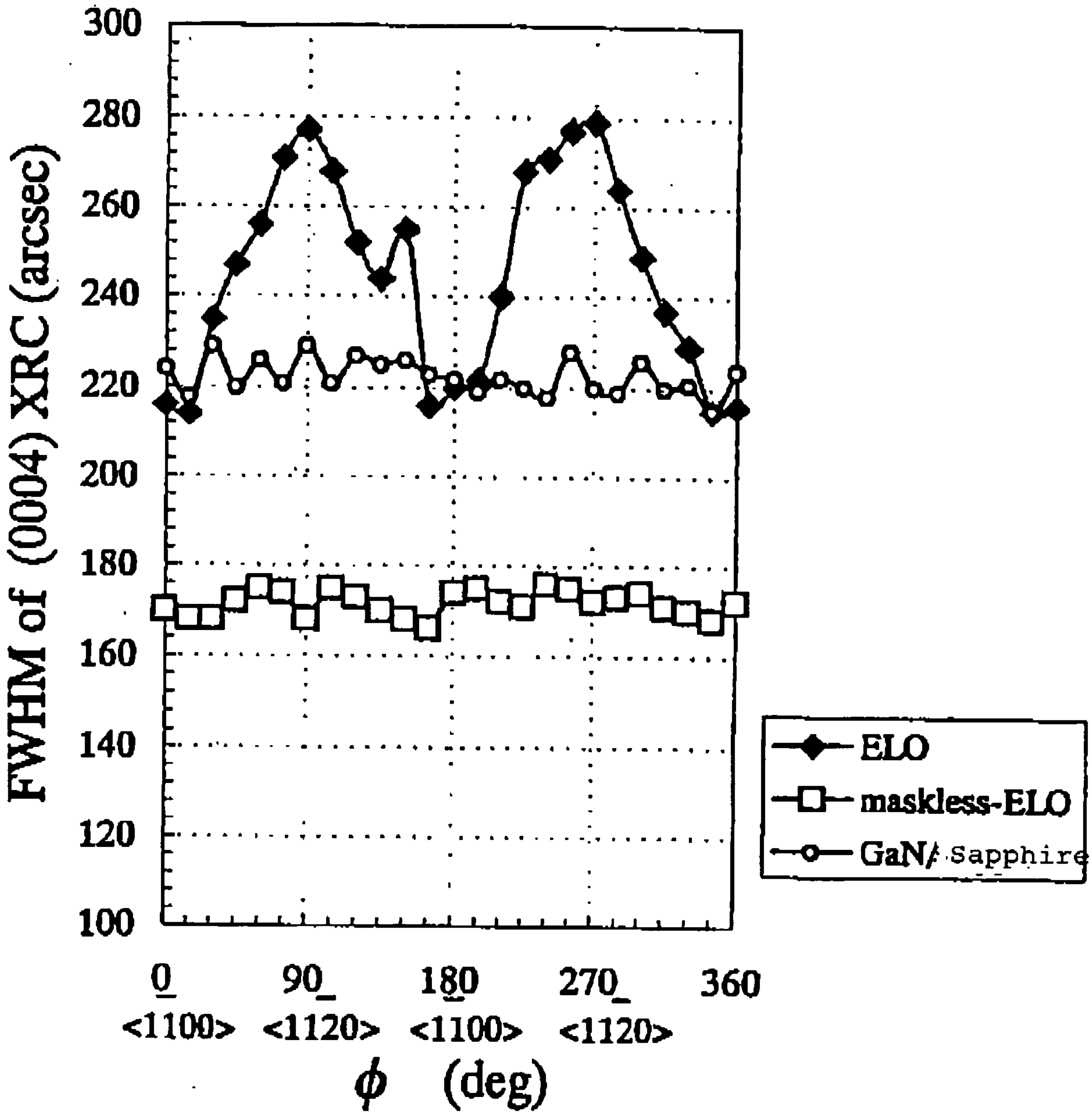

300
280
260
240
220
200
180
160
140
120
100
FWHM of (0004) XRC (arcsec)
ELO
maskless-ELO
GaN/Sapphire
0
90
180
270
360
<1100>
<1120>
<1100>
<1120>
φ (deg)

FIG. 5

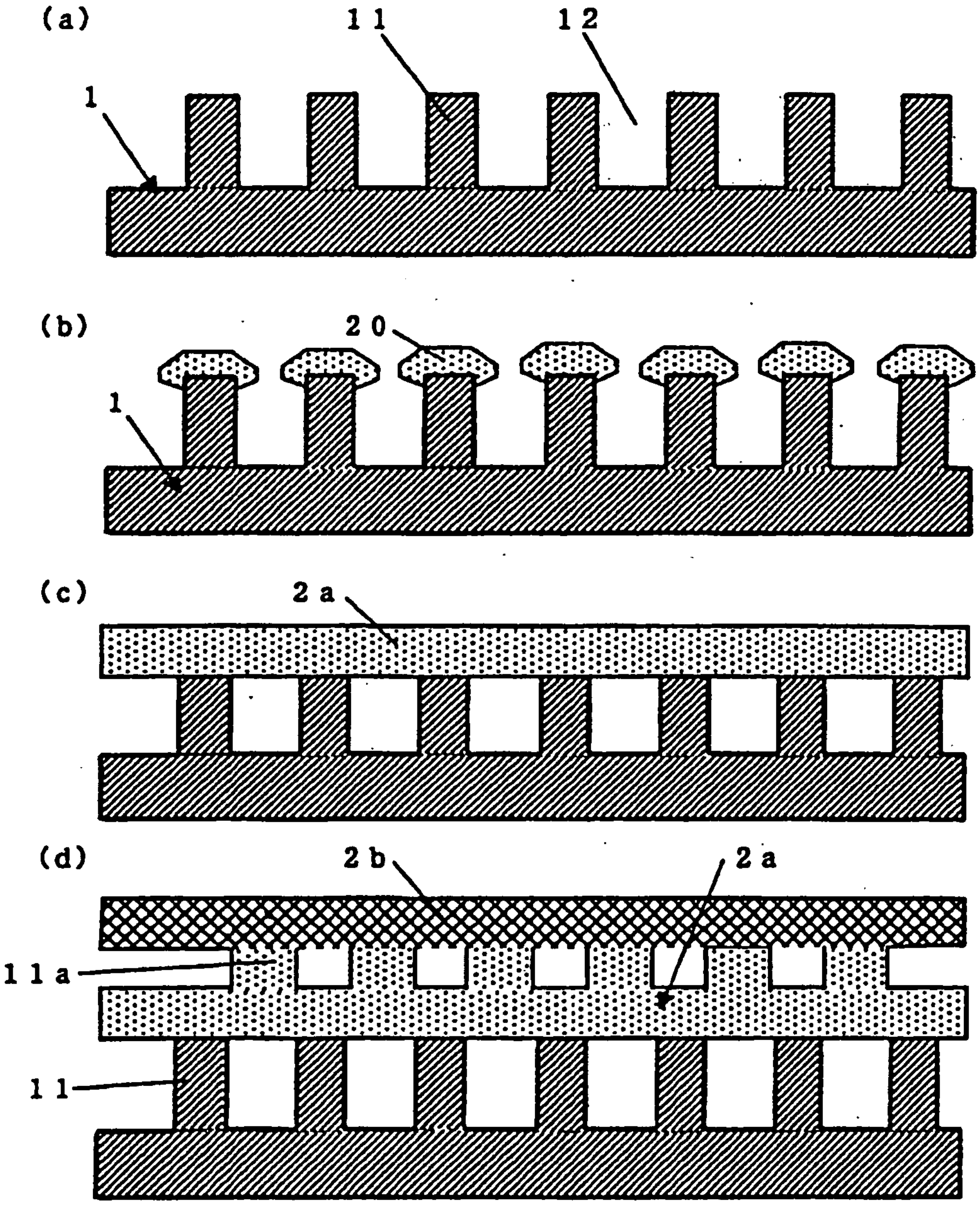


FIG. 6

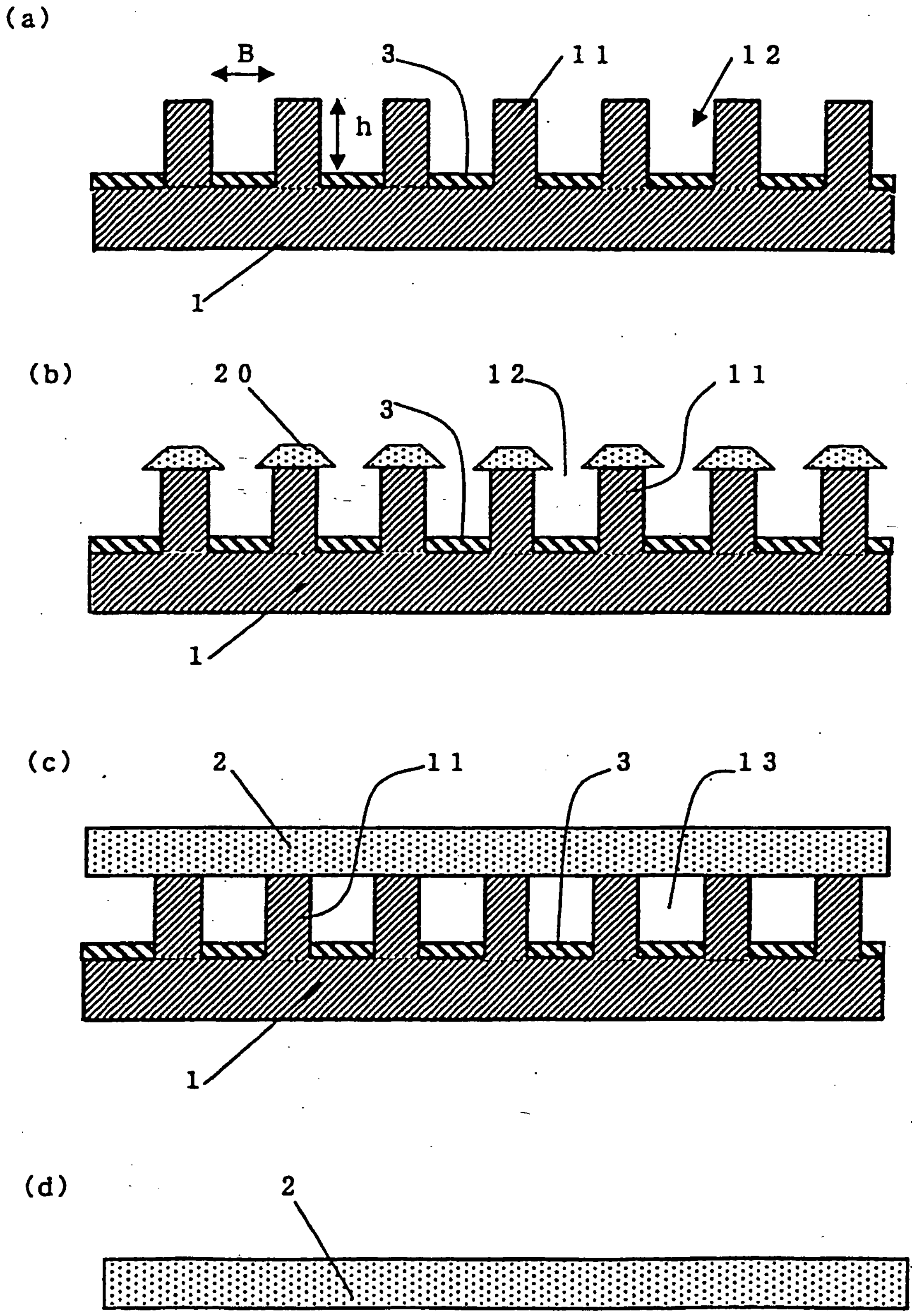
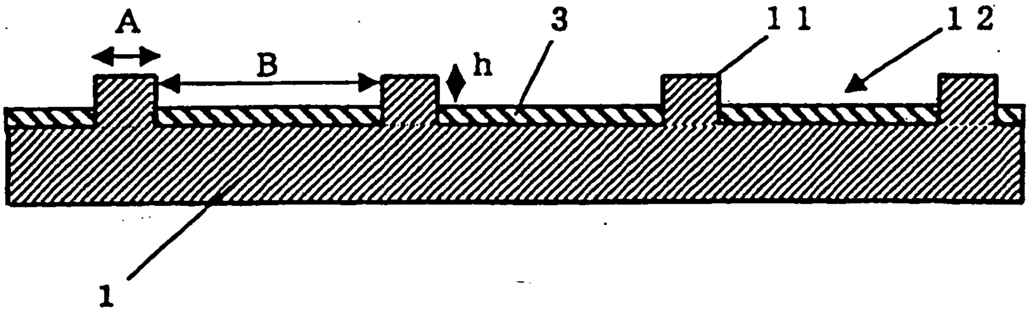
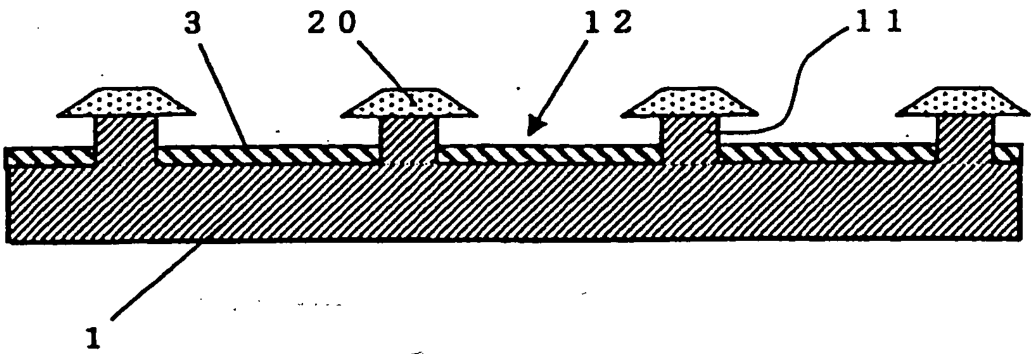


FIG. 7

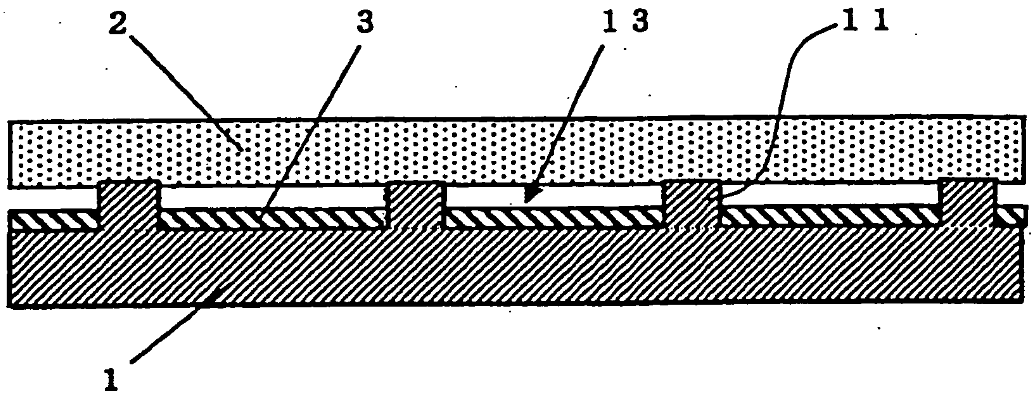
(a)




(b)




(c)




(d)

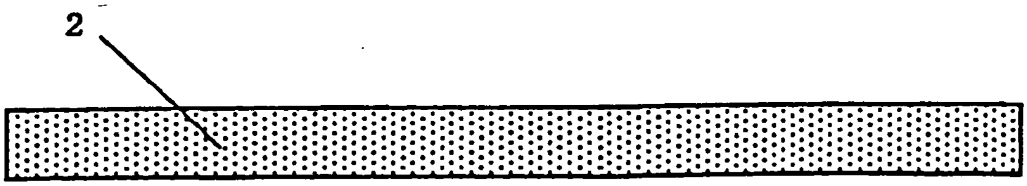


FIG. 8

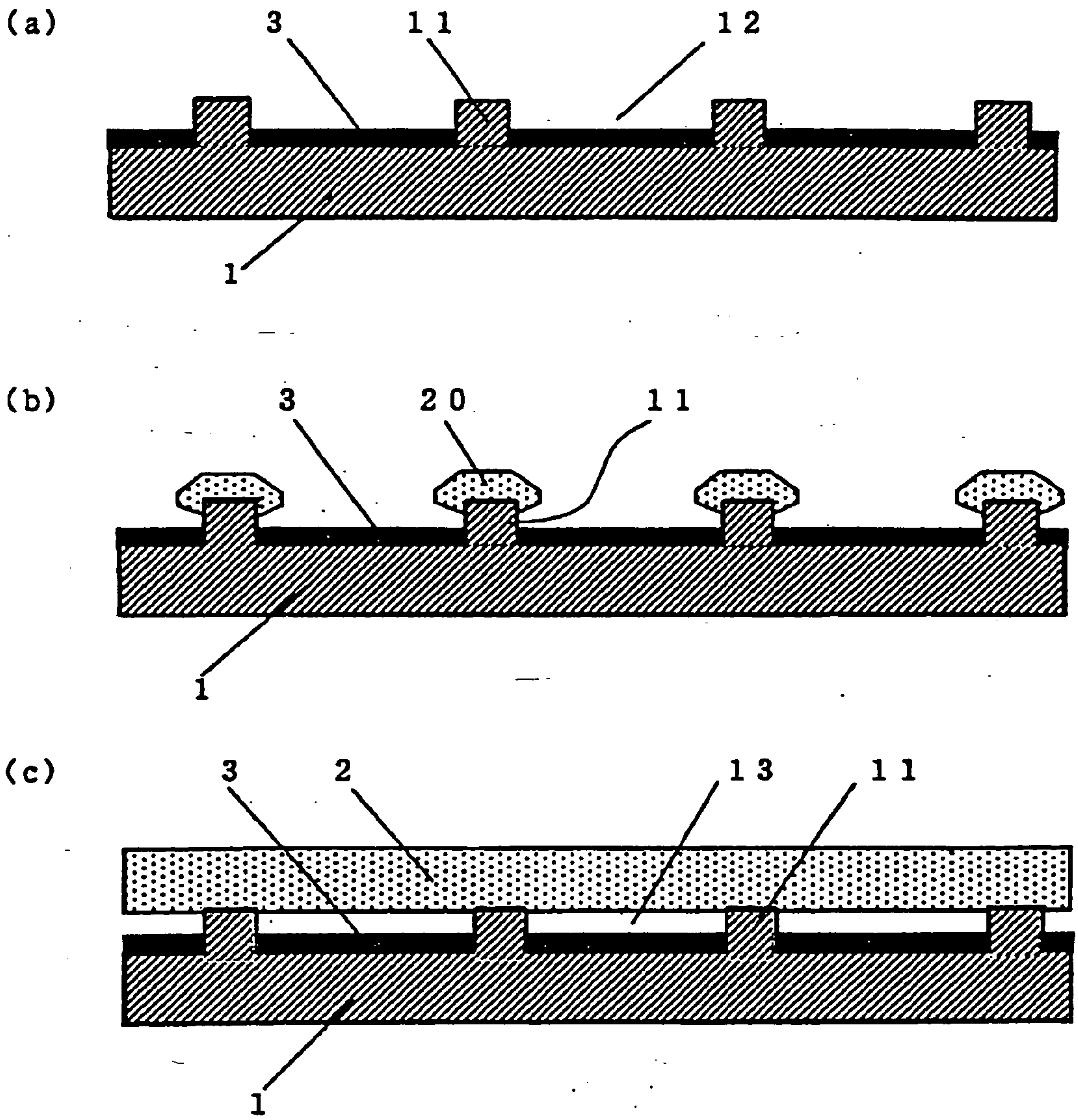


FIG. 9

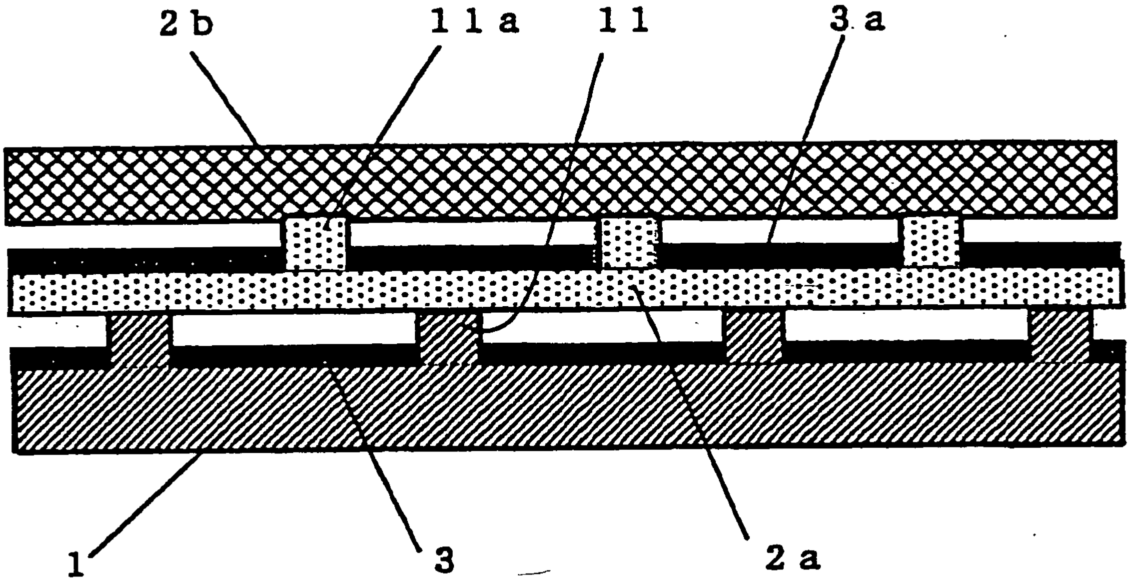
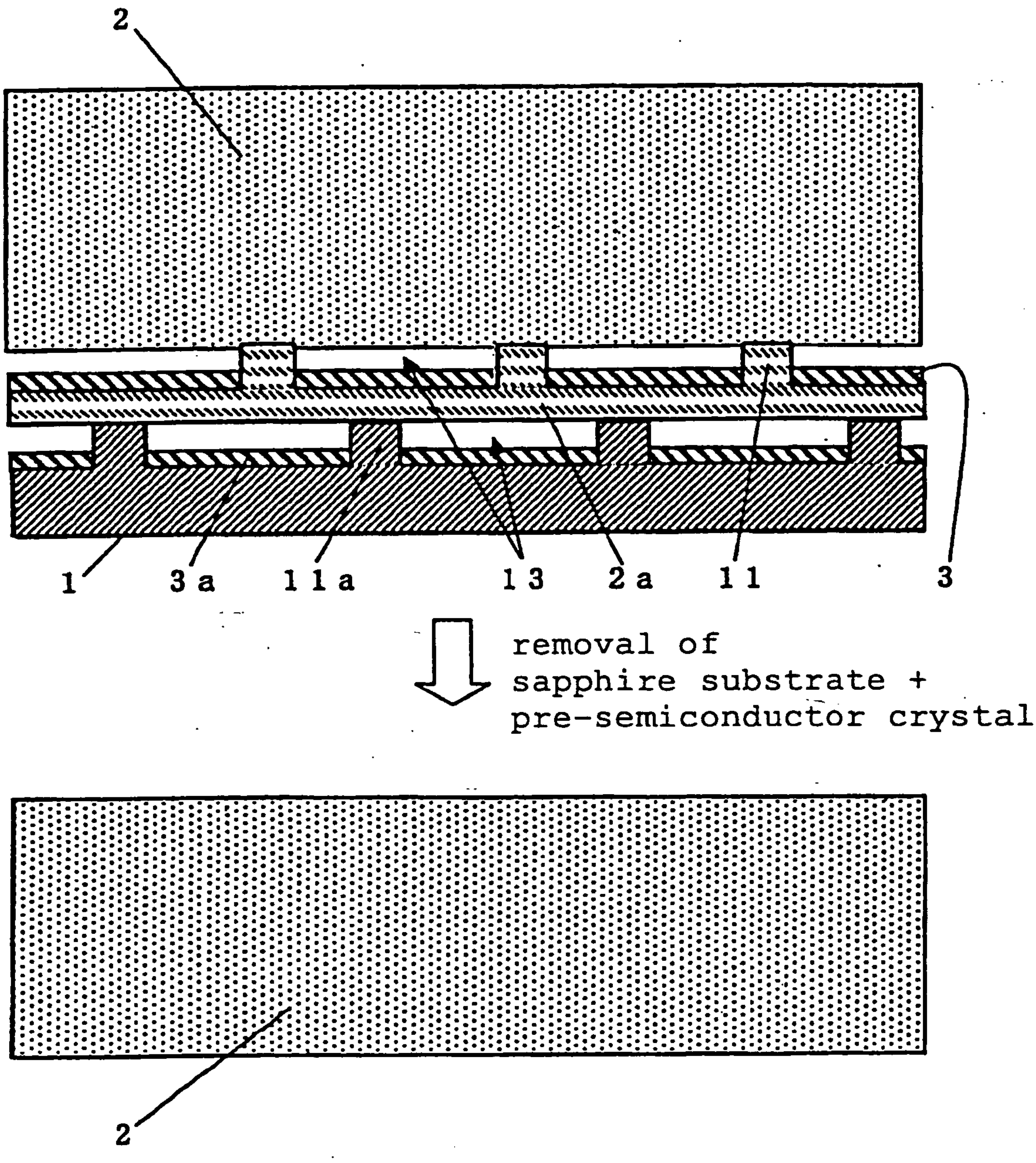


FIG. 10


2
1
3a
11a
13
2a
11
3
removal of
sapphire substrate +
pre-semiconductor crystal
2

## REFERENCES CITED IN THE DESCRIPTION

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